PULSED POWER EDUCATION AT MISSISSIPPI STATE UNIVERSITY

David B. Miller, Stanislaw Grzybowski, A. Lynn Libby

Department of Electrical Engineering
Mississippi State University
P. O. Drawer EE
Mississippi State, MS 39762

Abstract

In the High Voltage Engineering Program at Mississippi State University, pulsed power education is carried out at the undergraduate, graduate and postgraduate levels, and is performed through formal courses, short courses, research projects and testing.

The dual level course, Insulation Coordination, treats the relationship of transients on a system to the ability of system components to withstand these transients or to protect against these transients. The graduate course, High Voltage Engineering, goes into more depth regarding sources and analysis of transients, breakdown of insulation under fast transient voltages, and design of pulsed circuits. Both courses involve laboratory exercises, including impulse generator design and measurement of pulses. A second graduate course, Advanced Power Systems Analysis, uses the EMTP computer program to educate the students on the phenomena of switching and pulse transmission in electrical networks.

Several experimental research projects have been related to pulsed power. The graduate and undergraduate students working on these projects gain valuable knowledge and experience while carrying out these activities. Research topics include: pulsed corona discharge on coaxial and wire transmission lines, measurement and analysis of fast switching transients in SF6 transmission systems, and response of distribution components to steep-front high-voltage pulses.

Finally, students gain additional experience participating in testing activities. These include impulse breakdown and aging of cable, insulators, transformers, arresters and transmission line hardware.

Objectives

Pulsed power education at Mississippi State University is carried out within the MSU High Voltage Engineering Laboratory, a facility of the Department of Electrical Engineering. A major objective of this educational program is to acquaint power majors with transient power events such as lightning, switching and faults, occurrences which they are very likely to encounter later in their careers. Another goal is to introduce the electrical engineering students to power device design and transient measurement techniques, which will be important to them whether they associate themselves with the manufacturing or user side of engineering. Finally, an objective is to get engineering students interested in research by involving them in the advancement of pulsed power engineering.

These objectives are met by an inter-related combination of formal classroom lecture courses, organized laboratory sessions, student projects and student participation in research. These activities are described in more detail in the following paragraphs.

Formal Courses and Laboratories

The formal courses in high voltage are integrated into the power curriculum and contain elements of traditional and pulsed power. The dual level course, Insulation Coordination, has the objectives to present the factors causing insulation failure in power systems and to consider methods to prevent such failures. Overvoltage sources such as lightning, switching and unbalanced faults are studied as causes of insulation failure. The students then explore insulation design and characteristics of arresters as methods to prevent insulation failure. The concept of Basic Impulse Insulation Level (BIL) is introduced as the analytical tool to evaluate insulation capability. The design of impulse generators and standard insulation tests are studied both in the classroom and in the laboratory.

The graduate course, High Voltage Engineering, goes into more depth regarding pulsed power generation, measurement and application. Theoretical design concepts related to steep-front generators and wide-bandwidth dividers are verified by laboratory exercises. The theories of breakdown under dc and impulse voltages are developed using Townsend and Raether-Meek theories. Methods for field analysis and design of insulation systems are derived and applied to practical situations. Students also go through the development of arc and corona analytical models.

Both of these courses, as well as other related power courses, utilize the Mississippi State High Voltage Laboratory for experimental demonstration of the analyses and techniques brought out in lectures and reading assignments. This laboratory is housed in a shielded 80 ft x 110 ft area with 50 ft overhead clearance and a welded ground grid. The major sources are a 3 MV, 56 kJ Marx type impulse generator, a 1 MV 60 Hz transformer, and a 1050 kV dc supply. Wide-bandwidth analog and digital oscilloscopes, dividers and current transformers are available for acquisition of pulsed power signals.

Analytical Skills

The pulsed power engineering student must become familiar with a number of analytical tools, including Fourier and Laplace transforms, convolution, characteristics of waves on lines, and mapping of electric fields. He or she is introduced to these concepts within the sequence of circuits, fields and network courses required of all electrical engineering students. These are then applied specifically to pulsed high power situations in the Insulation Coordination and High Voltage Engineering courses offered to seniors and graduate students.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 1989**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Pulsed Power Education At Mississippi State University**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Electrical Engineering Mississippi State University P. 0. Drawer EE Mississippi State, MS 39762**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT
In the High Voltage Engineering Program at Mississippi State University, pulsed power education is carried out at the undergraduate, graduate and postgraduate levels, and is performed through formal courses, short courses, research projects and testing.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

A special skill which has been found to be of extensive use in the design and analysis of pulsed power circuits and phenomena is the application of the ElectroMagnetic Transients Program (EMTP). Figure 1 is an EMTP computation of the voltage input to and output from a line pulser into an arrester. This was useful in understanding the behavior of the line pulser circuit developed in our laboratory and described in conjunction with Figure 3.

Generators

A key element of any pulsed power activity is the source of the pulse, and students must be aware of the components and systems necessary to generate power pulses. Such topics as energy storage capacitors, low inductance design, corona shielding, gas insulation and gap switches are introduced. Students become familiar with Marx circuits, line pulsers and wave shaping. Safety must be a continuing aspect of the pulsed power educational program.

These concepts can be introduced in the classroom, but the student does not really grasp an understanding of these components and systems until he or she has actually participated in laboratory exercises using these devices. The formal weekly laboratory which accompanies the High Voltage Engineering course involves each student in setup and measurements related to pulsed voltage and current measurement. Figure 2 shows a class adjusting the 3 mV, 56 kJ Marx generator.

More advanced generators for special purposes are encountered by students during their involvement in research programs. As an example, a steep-front line pulser is shown in Figure 3 being set up by students for arrester testing. This pulser can deliver voltage pulses with risetimes less than 50 ns and voltages of nearly a half million volts. The student will acquire an understanding of wave impedance and propagation characteristics, low inductance circuits, pressurized gap switches and transient voltage capability of polyethylene-insulated high voltage cable while working with this generator.

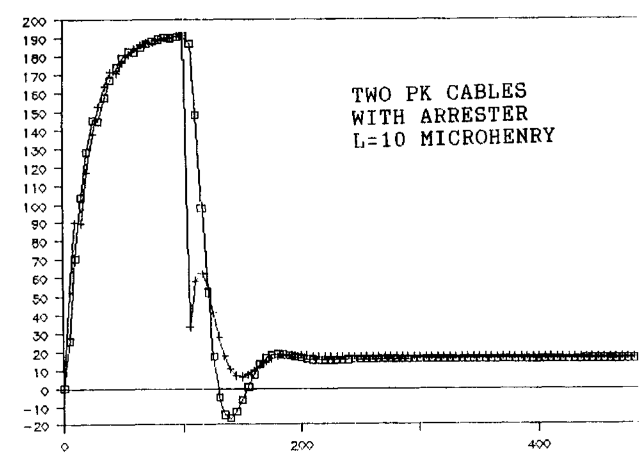

Figure 1 EMTP simulation of line-type pulser switched at one microsecond into a 20 kV MOV arrester in parallel with a terminated 15 kV cable. Voltages at input to and output from the pulse line are plotted. The charge source is a 25 nF, 200 ohm, 10 microhenry Marx generator.

Figure 2 Graduate class preparing the 56 kJ, 3 MV Marx generator for laboratory experiments.

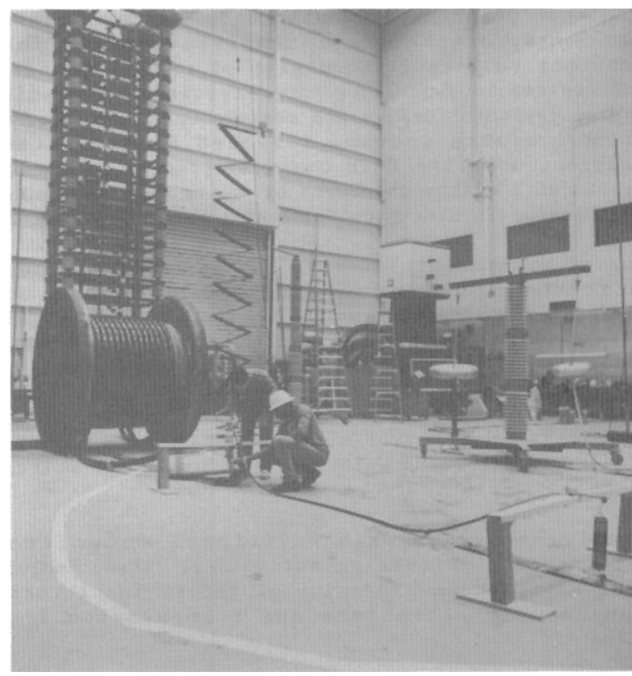

Figure 3 Students setting up the steep-front line pulser to test an arrester in parallel with a terminated 15 kV cable.

Instrumentation

Measurement of pulsed power parameters becomes increasingly more difficult, and more interesting, and more expensive, as higher powers and faster circuits are required. Traditionally, low inductance, wire-wound voltage dividers and low inductance resistive shunts have been used to measure high voltage and high current impulses in the microsecond range, and these are still useful for instructional and research applications at higher frequencies. The student should understand the high frequency analysis of dividers in order to appreciate the steps which are necessary to achieve accurate measurement of voltage and current at high power levels and very short durations. Availability of such instruments as liquid

dividers and wide-band current transformers in the instructional and research laboratories is important to the education of the future pulsed power engineer. Figure 4 shows students deciding how to install a high frequency current transformer with electro-optical transmitter and fiber-optic cable on a pulsed power line which will carry as high as 20,000 amperes and a half million volts.

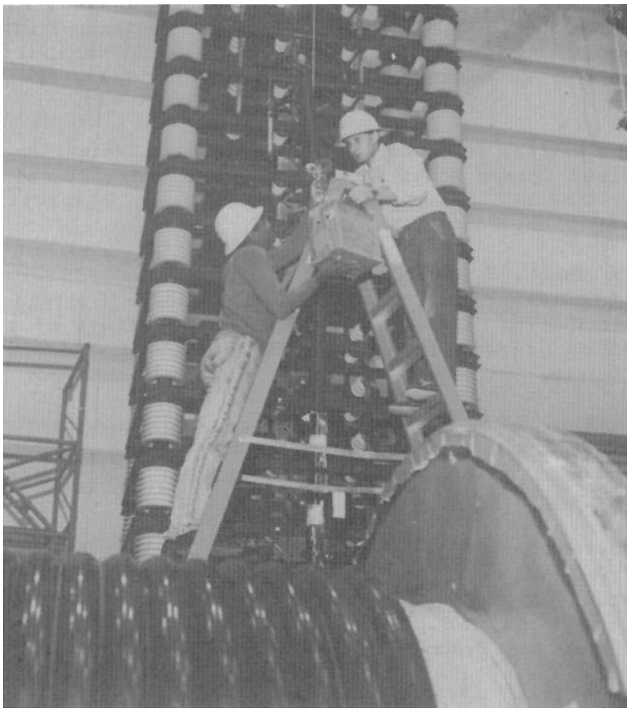

Figure 4 Student assistants deciding how to install a current transformer and fiber-optic transmitter to measure pulse currents into the line pulser.

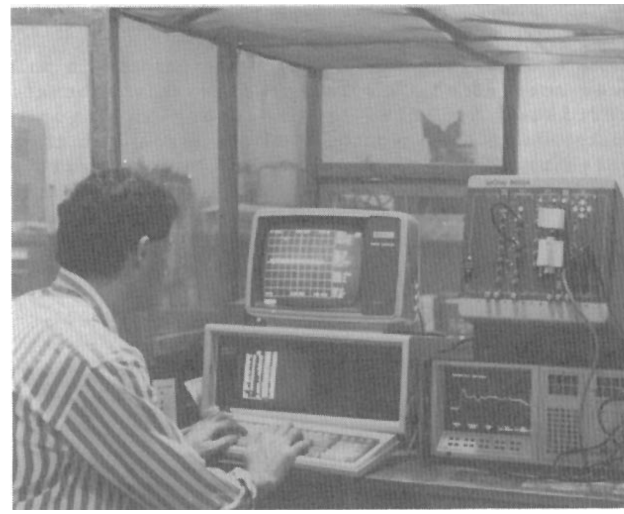

Figure 5 Transient data acquisition system in the Mississippi State University High Voltage Laboratory. A student prepares to transfer a pulse voltage waveform from the .74 ns digitizer to the computer. The 100Ms/s digitizer is also available for waveform acquisition.

Figure 6 illustrates a waveshape of the voltage during high current pulsing of an MOV arrester. Note that the students who ran this experiment had to design and build the liquid divider, set up the pulser and cabling to the digitizer, select attenuation and all oscilloscope settings, fire the shot, transfer the data to the computer (after considerable effort getting data transfer software to perform) and plot the curve using a commercial spreadsheet program.

Data

Most pulsed power and high voltage laboratories are moving away from the traditional analog oscilloscope and photography of the transient waveshape and going to digital signal acquisition and storage. The stored digital waveshape can be inspected immediately after the shot, as with photography of an analog signal, but it also remains available for subsequent observation and mathematical processing in a manner not easily accommodated by a photograph.

Some digitizers and associated PC type computers are shown in Figure 5 being adjusted by students in the Mississippi State laboratory. During use of this type of equipment, the students become familiar with proper grounding and shielding, signal cable, coaxial connectors and attenuators necessary to deliver the signal to the digitizer without interference and at the proper voltage level. Set up of the digitizer is important. the student has the opportunity to learn that correct digitizing rate, total samples, voltage range and triggering must be set properly in order to acquire the desired signal. Software must be installed in the computer and properly coordinated with the digitizer in order to transfer the waveshape to storage and further analysis in the computer.

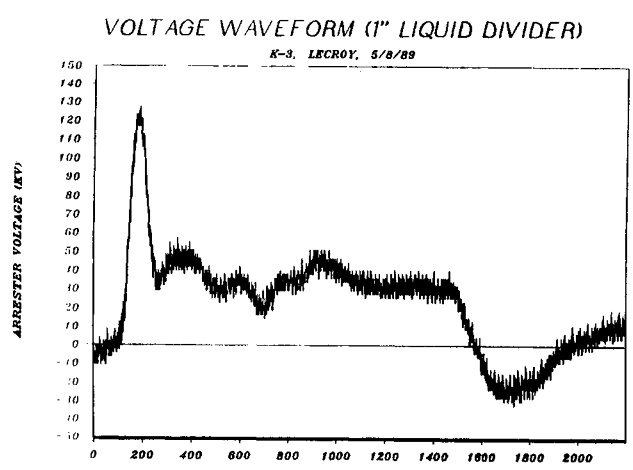

Figure 6 A typical arrester steep-front waveform acquired by the .74 ns digitizer, after transfer to the computer and replotting.

Examples of Student Involvement

We have described how students participate in pulsed power activities through formal weekly laboratory exercises, typified by the scene in Figure 2. Undergraduate and graduate students also learn through design projects, in which individual students are guided by a professor and for which they earn credit hours. Some pulsed power related projects which have been carried out recently include:

- Treeing in polyethylene cable due to pulses.
- CFO of distribution insulators due to steep-front pulses.
- Pressurized gap design and testing.
- Computer analyses of impulse generator circuits using SPICE, EMTP and NEC programs.
- Ultra-violet light triggered spark gap switch.
- Stacked transmission line pulser; analysis and testing.
- Setup and testing a Kerr cell for short duration photography of pulsed discharges.
- Design and testing a field sensor for measurement of transient voltages.

Undergraduate students also gain experience in pulsed power engineering by being employed as engineering aides in the laboratory. Typically, ten to fifteen electrical engineering students are employed, approximately ten hours per week to help with experimental design, setup, testing and analysis. In this way, they become familiar with all aspects of pulsed power engineering.

Completion of masters' theses and doctoral dissertations represent the highest level of graduate student participation in pulsed power research. Presentations and publications of the results of these research programs, shown in the accompanying bibliography, are final steps in disseminating the knowledge gained.

Acknowledgements

Sponsoring agencies include: EPRI, DOE, Southeastern Electric Exchange, electric utilities and manufacturers.

Bibliography

D.B. Miller, A.E. Lux, S.Grzybowski, P.R. Barnes, "The Effects of Steep-Front, Short-Duration Impulses on Power Distribution Components," IEEE/PES Summer Meeting, Long Beach, CA, July 10-14, 1989.

Andre E. Lux, "The Effect of Steep-Front Short-Duration Impulses on Distribution System Components," M.S.E.E. Thesis, Mississippi State University, May, 1989.

E. Ray Ross, "A Study of Lightning Strengths Provided by Multiple Series Dielectrics Used in Overhead Distribution Configurations," M.S.E.E. Thesis, Mississippi State University, May, 1989.

A.E. Lux, D.B. Miller, D.L. Kempkes, "The Effects of Steep-Front Short Duration Pulses on Polyethylene Cable Insulation," Proceedings - 1989 IEEE Southeastcon, Columbia, SC, April 9-12, 1989.

D.B. Miller, P.B. Jacob, Jr., S. Grzybowski, A.L. Libby, "High Voltage Engineering at Mississippi State University," 1989 IEEE Transmission and Distribution Conference, New Orleans, LA, April 2-7, 1989.

D.B. Miller, S.L. Sumrall, "Experimental Evaluation of Pulsed Corona Model Parameters," Conference Record of the 1989 IEEE International Symposium on Electrical Insulation, Boston, MA, June 5-8, 1988.

P.B. Jacob, S. Grzybowski, L. Libby, P.K. Barsley, "Experimental Studies of Critical Flashover Voltage on Distribution Line Construction," Proceedings of the IASTED Conference on High Technology in The Power Industry, Scottsdale, Arizona, March 1-4, 1988.

David L. Kempkes, "Generation of Steep-Front Impulses and Measurement of Their Effects on Power Distribution Cable Polyethylene Insulation, M.S.E.E. Thesis, Mississippi State University, December, 1987.

D.B. Miller, P.B. Jacob, S.L. Sumrall, "Use of Fiber-Optic Communications Link in Measurement of Pulsed Corona Current on Long Horizontal Conductors in Air," Fifth International Symposium on High Voltage Engineering, Braunschweig, FRG, August 24-27, 1987.

D.B. Miller, P.M. Harrison, "Measurement and Modelling of Switching Parameters in Gas-Insulated Transmission Lines," Proceedings - 1987 IEEE Southeastcon, Tampa, FL, April 5-8, 1987.

Paul M. Harrison, "Measurement and Analysis of Disconnector-Induced Switching Transients in Gas-Insulated Systems," M.S.E.E. Thesis, Mississippi State University, August, 1986.

Antoine H. Hayek, "Design and Frequency Response Characteristics of Different E-Field Sensors in a Gas-Insulated Transmission Line," M.S.E.E. Thesis, Mississippi State University, August, 1986.

D.B. Miller, D.L. Gambrell, "Steep Wavefront Discharges in a Coaxial Electrode System," Conference Record of 1986 IEEE International Symposium on Electrical Insulation, Washington, DC, June 9-11, 1986.

David L. Gambrell, "Measurement and Analysis of Pulsed Corona Discharges for a Coaxial Electrode Configuration," M.S.E.E. Thesis, Mississippi State University, May, 1986.

D.L. Gambrell, D.B. Miller, "Techniques for the Measurement of Pulsed Corona in a Coaxial Electrode Configuration," Workshop on Measurement of Electrical Quantities in Pulsed Power Systems-II, National Bureau of Standards, Gaithersburg, MD, March 5-7, 1986.